VARIATIONS OF THE ELASTIC MODULUS OF AUTOMOTIVE STEELS AFTER YIELDING

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Overall aim

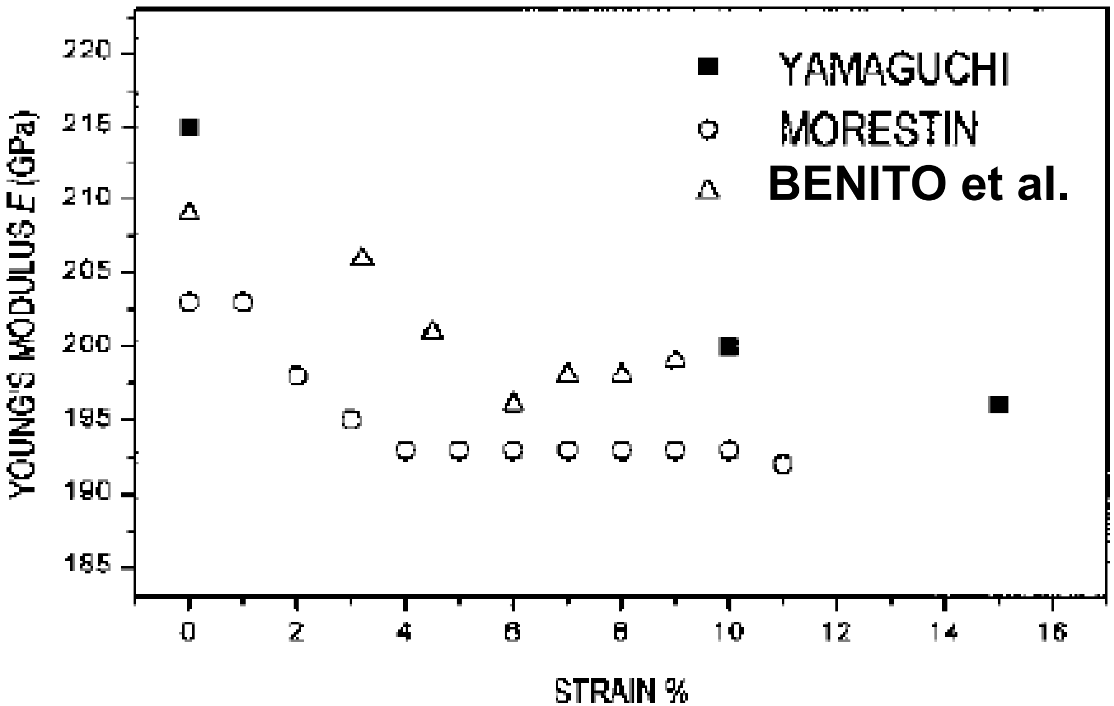
Accurate simulation of sheet cold forming processes for car body parts

FEM analyses sufficiently accurate to predict springback and to design *compensated* dies requires increasingly accurate material parameters

⇩

Accurate measurements of the elastic modulus on both virgin and already deformed steel

Previous works (1) – pure iron

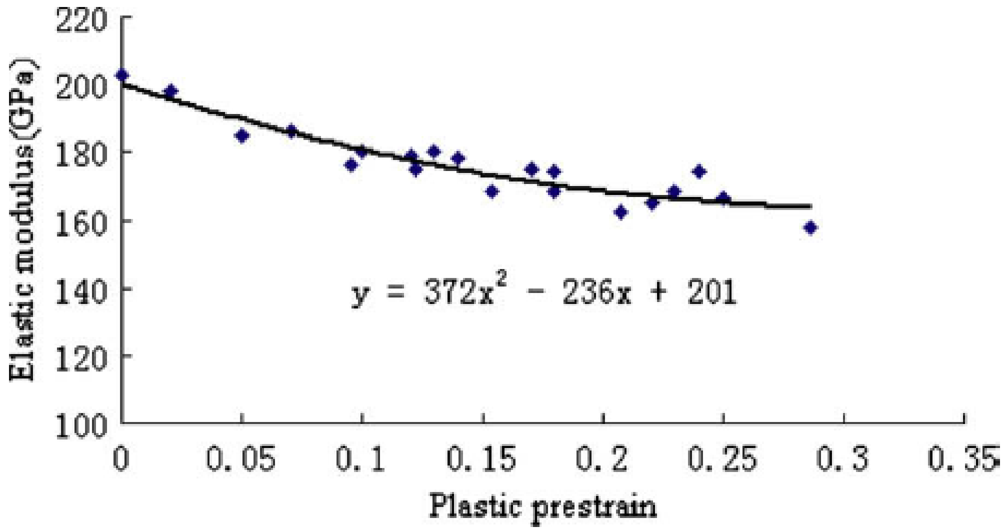


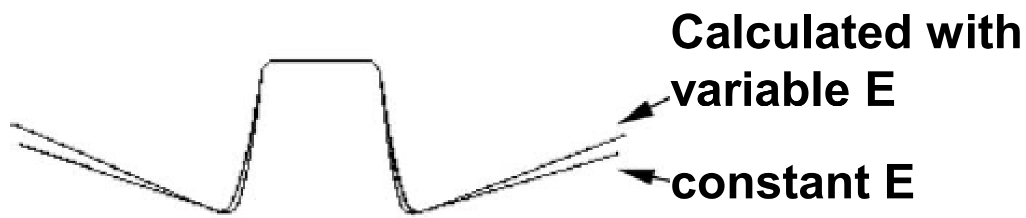
METALLURGICAL AND MATERIALS TRANSACTIONS A VOLUME 36A, DECEMBER 2005—3317

Change of Young's Modulus of Cold-Deformed Pure Iron in a Tensile Test

J.A. BENITO, J.M. MANERO, J. JORBA, and A. ROCA

Previous works (2) – TRIP steel, springback analyses





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Short Communication

Variation of elastic modulus during plastic deformation and its influence on springback

Hai Yan Yu *

Tested automotive steel sheets

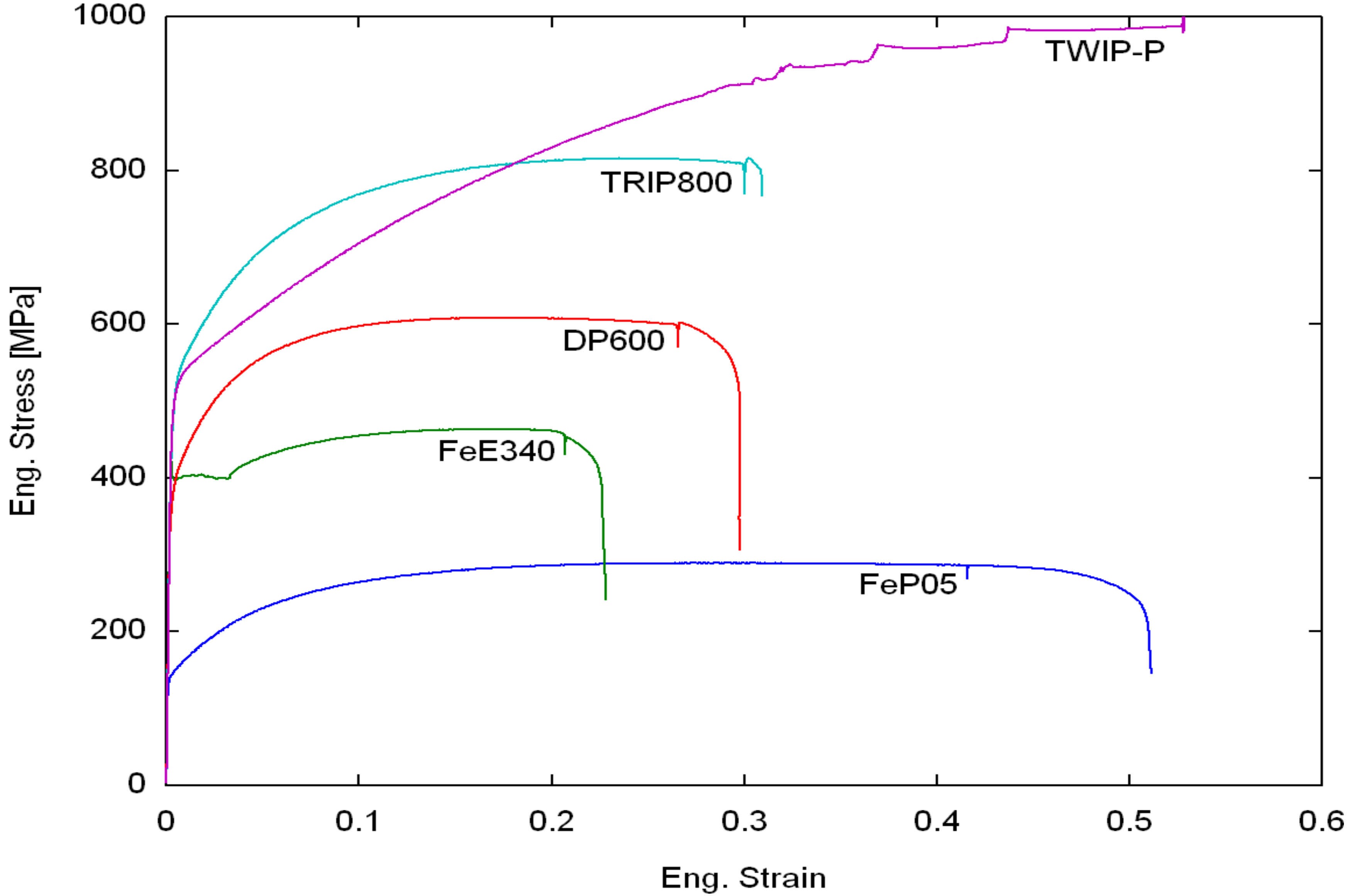
Grade	Thickn. [mm]	YS [MPa]			UTS [MPa]			e_t [%]		
		T	45	L	T	45	L	T	45	L
FeP05 (low carbon)	1	145	154	149	292	300	287	51	50	51
FeE340 (microalloyed)	1	433	394	384	476	455	469	23	36	37
DP600 (**D**ual **P**hase, ferrite & martensite)	1.55	388	387	388	615	610	614	30	21	25
TRIP800 (**TR**asformation **I**nduced **P**lasticity)	1	520	511	520	837	830	840	31	27	26
TWIP (18% Mn, 0.65% C, austenitic)	1.45	506	489	484	1010	997	993	53	63	47

As-received (i.e., cold rolled and heat treated) microstructure

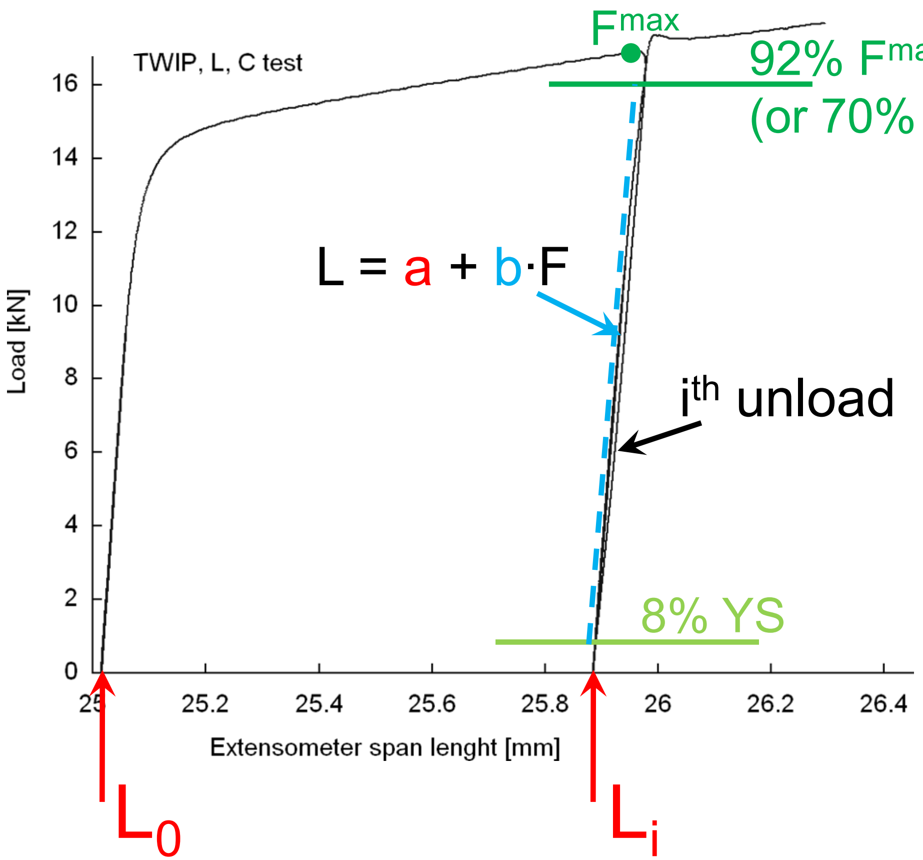
Protective Zn surface layers removed before testing

Tensile tests on 20 mm wide samples, with a 25 mm extensometer

Tested Materials – tensile curves (Orientation T)



Elastic modulus calculations



$L = L_i \cdot (1+\varepsilon) = L_i + L_i \cdot (\sigma/E)$

$L = L_i + (L_i \cdot F)/(E \cdot S_i)$

$L = L_i + (L_i^2)/(L_0 \cdot S_0 \cdot E) \cdot F$

(since $L_0 \cdot S_0 = L_i \cdot S_i$)

$L = a + b \cdot F$

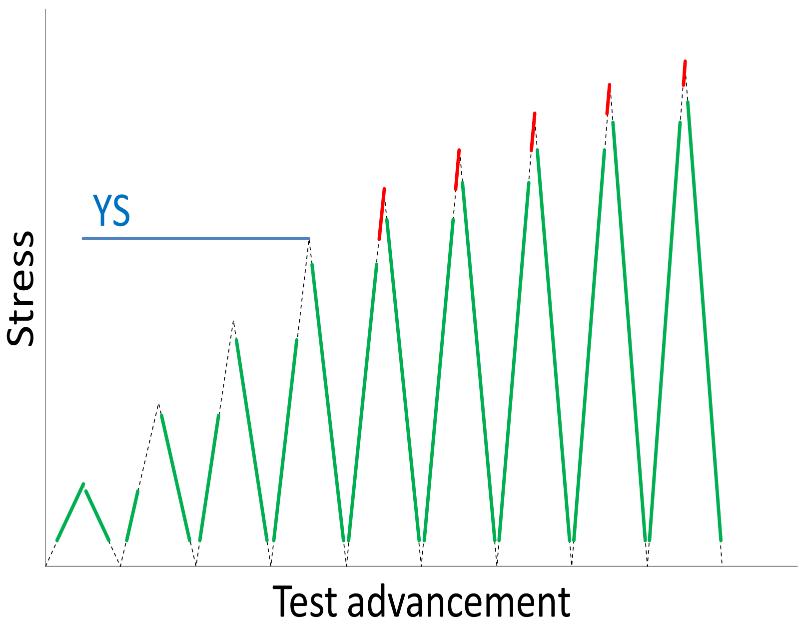
$\rightarrow L_i = a$

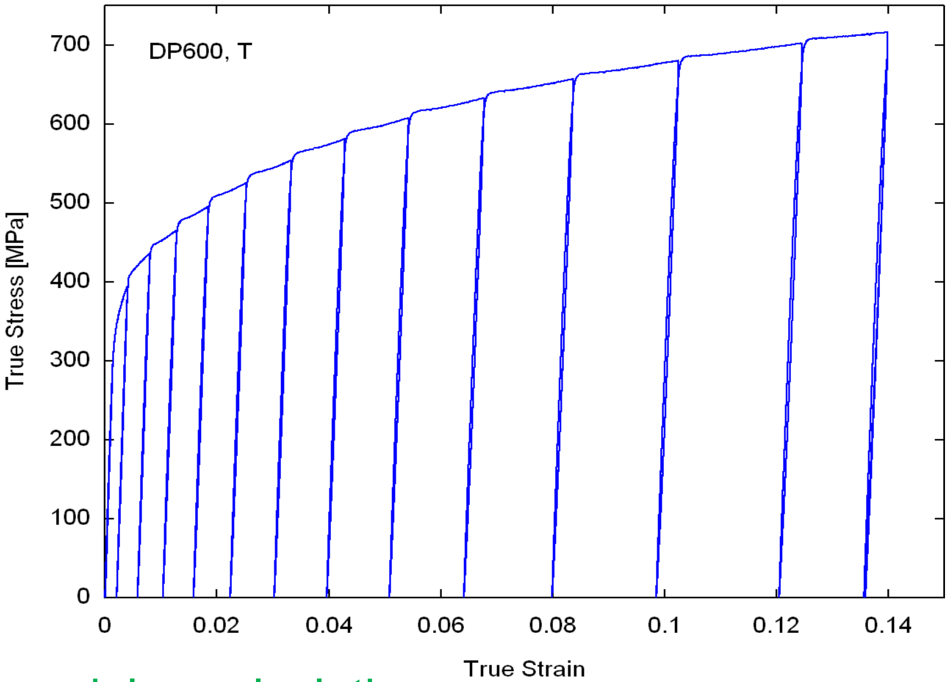
$\rightarrow$ Modulus $= E = a^2 / (L_0 \cdot S_0 \cdot b)$

$\rightarrow$ Pre-strain $= \varepsilon_i = \ln(L_i / L_0)$

Type I tests

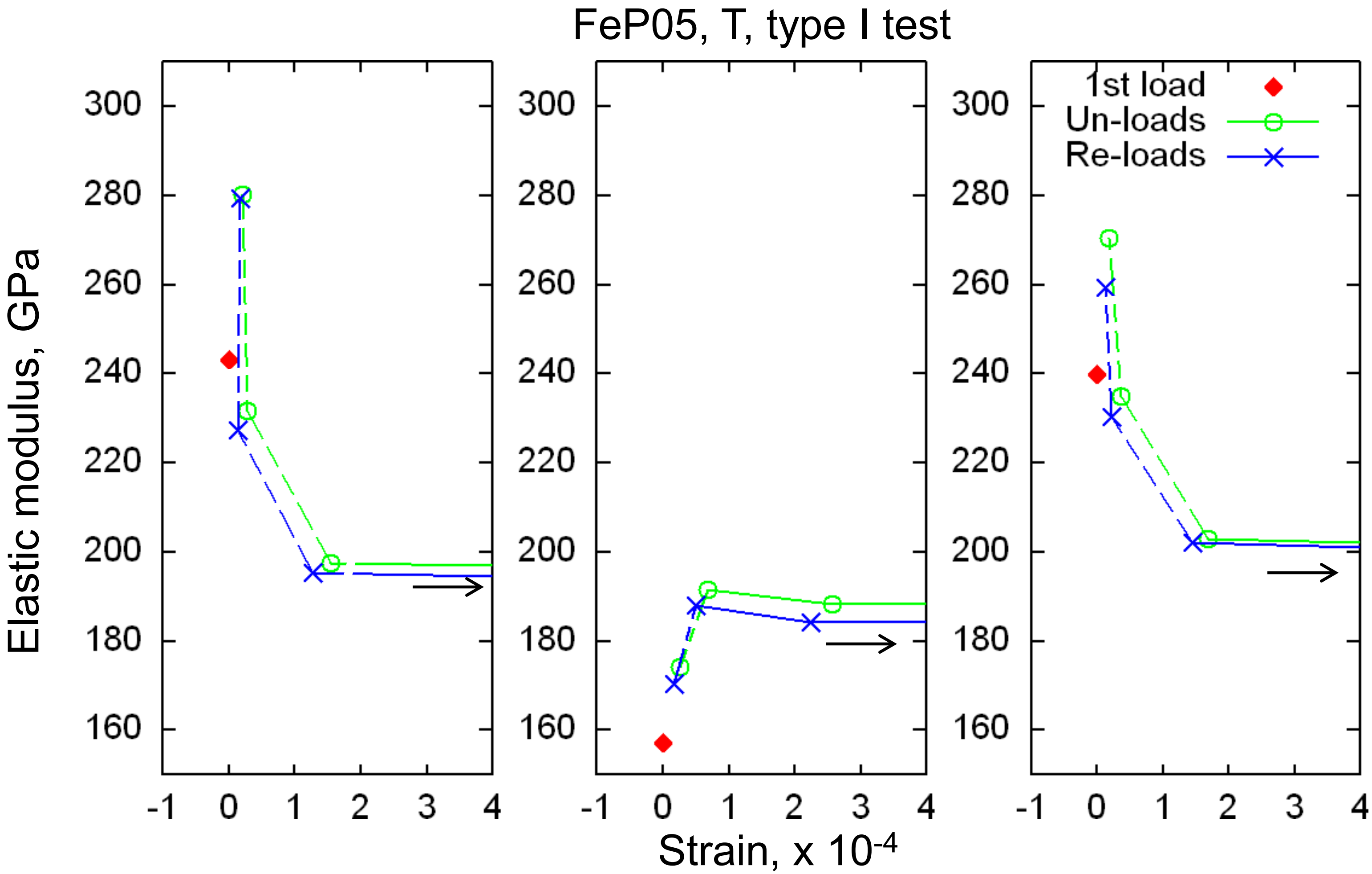
- unload – reload cycles up to ≈ 25, 50, 75 and 100 % of yield stress
- repeated plastic strain steps, starting from ≈ 0.004 true strain
  (each ≈ 20% larger than the previous one)
- one elastic unload-reload cycle after each step (and one final unload)
- elastic strain rate ≈10^{-4} s^{-1} in all cases





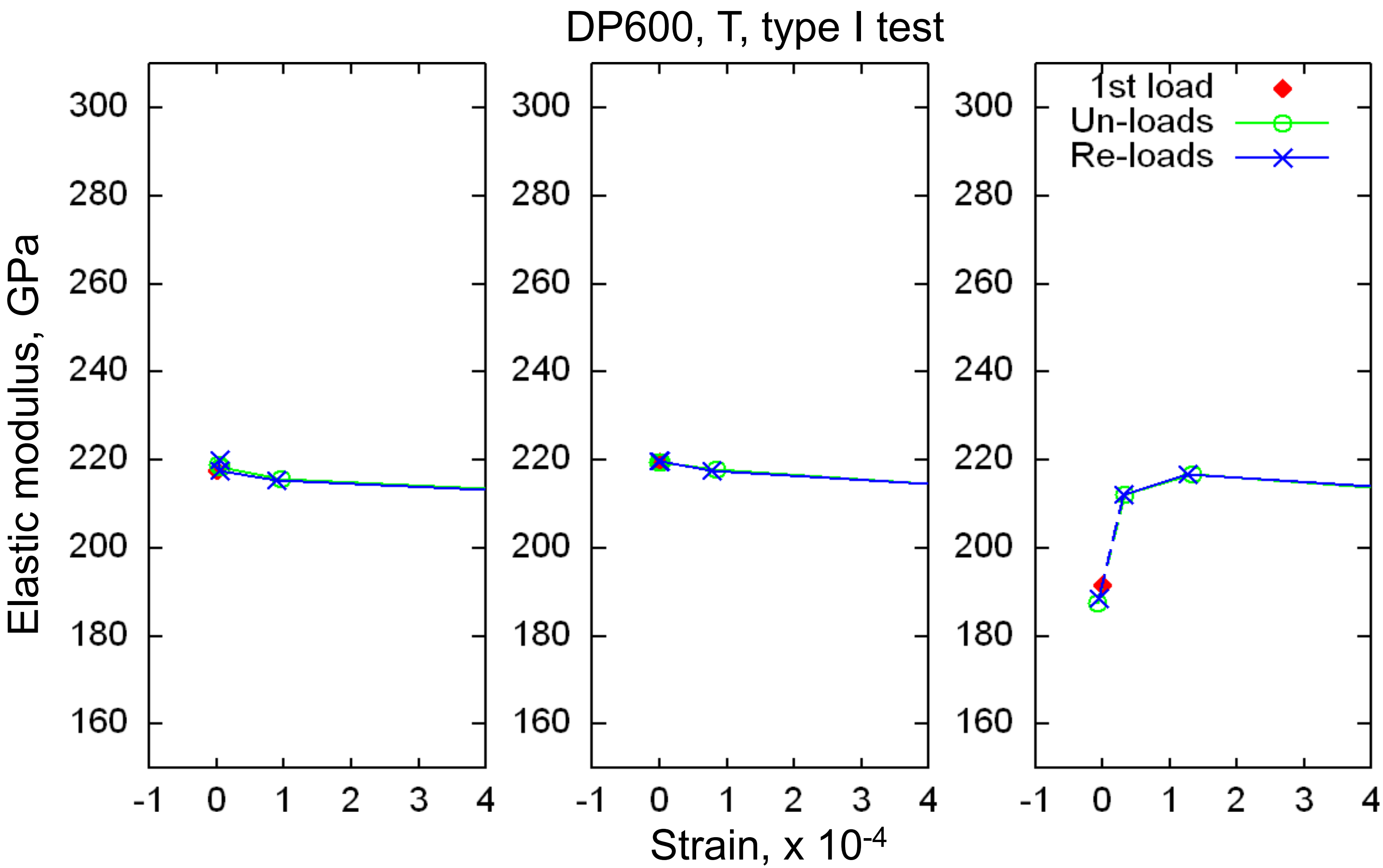
green lines: elastic modulus calculations

Results (1): elastic modulus from the 25, 50, 75 and 100% YS unload-reload cycles.



Large variations with increasing maximum stress, below YS, possibly due to straightening

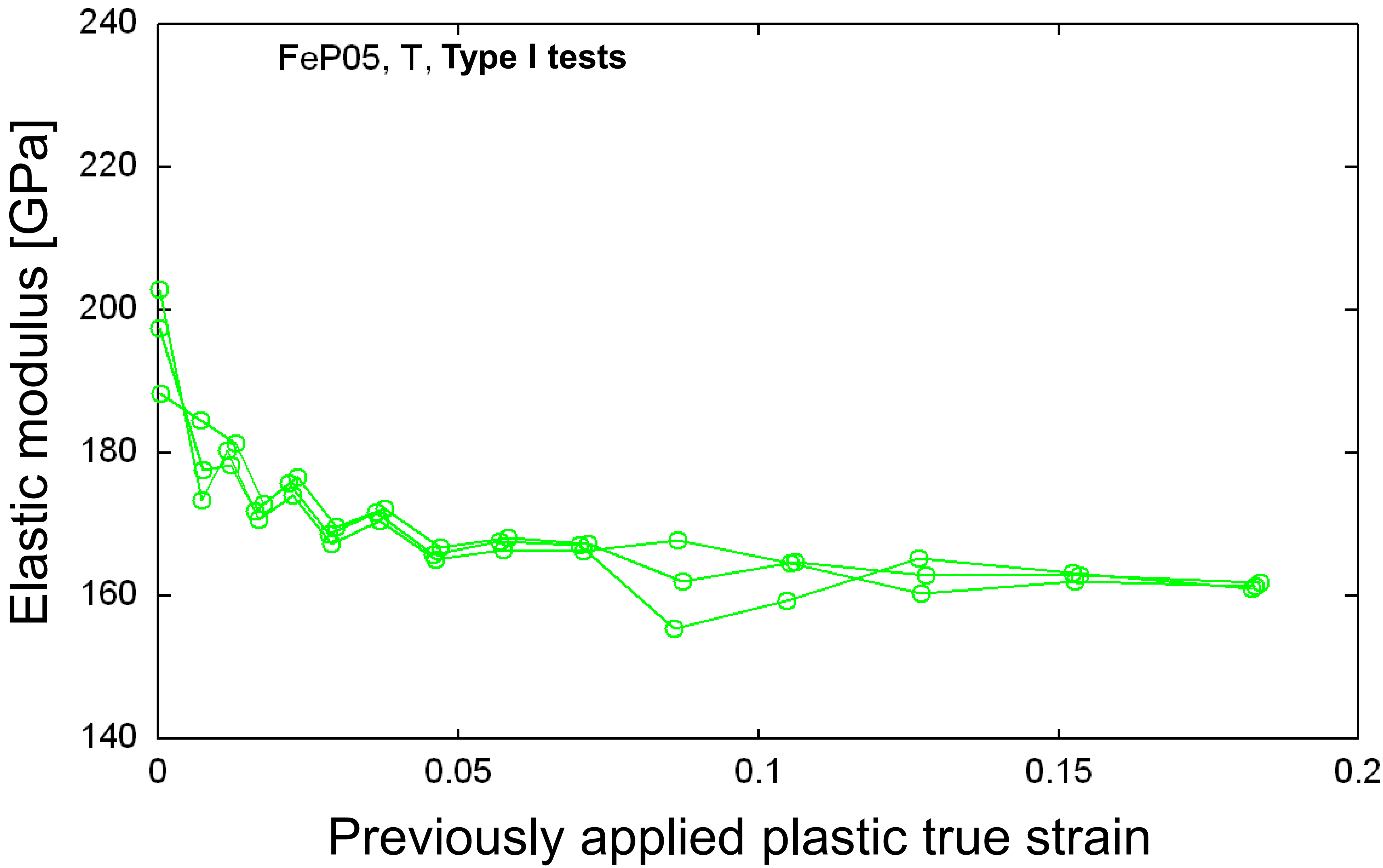
Results (1): elastic modulus from the 25, 50, 75 and 100% YS unload-reload cycles.



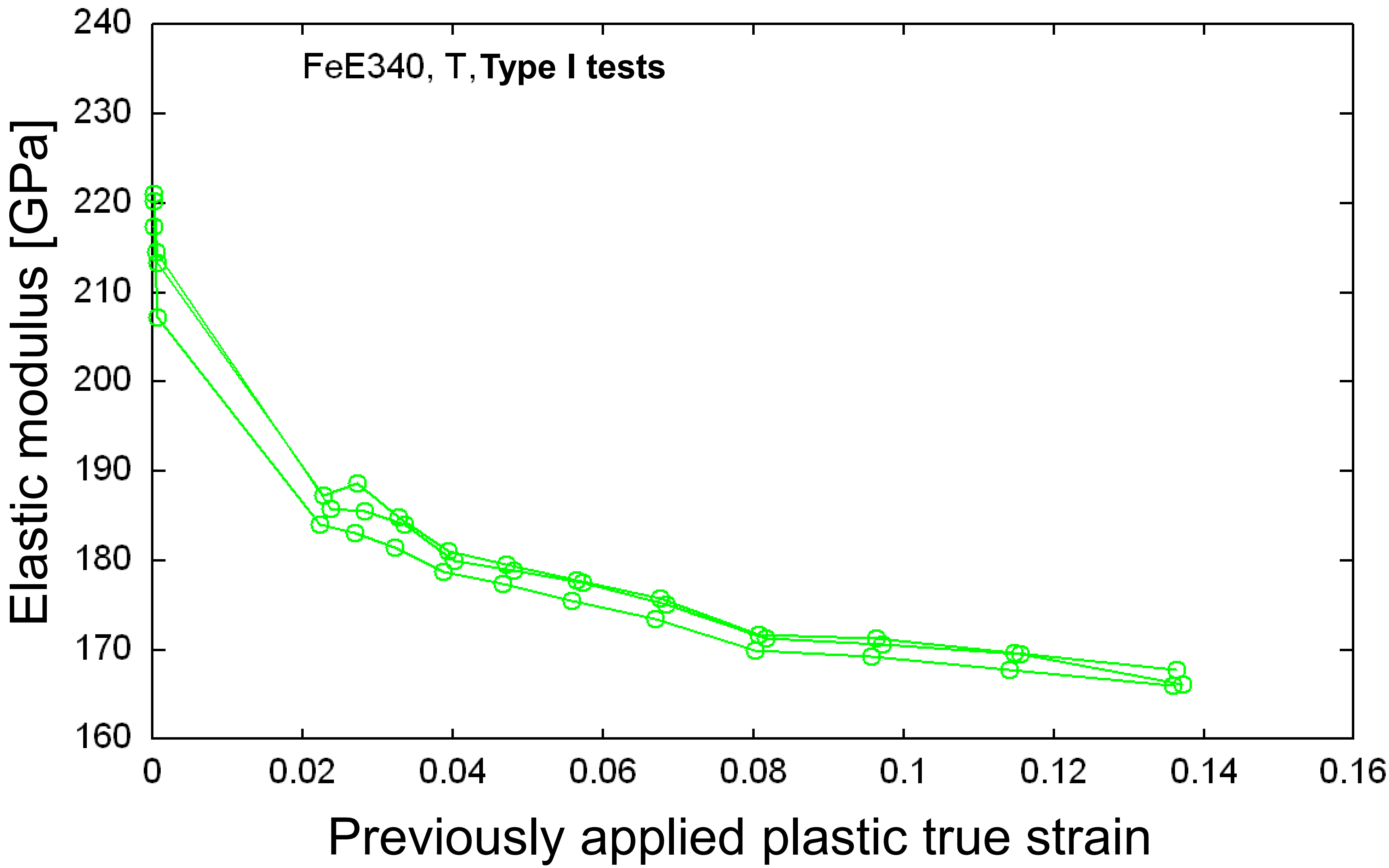
… but not in all cases.

The 0% strain modulus reported below will generally be for about 70% YS loading

Results (2): elastic modulus of the 1st unload after the plastic prestrain (3 samples)



Results (2): elastic modulus of the 1st unload after the plastic prestrain (3 samples)



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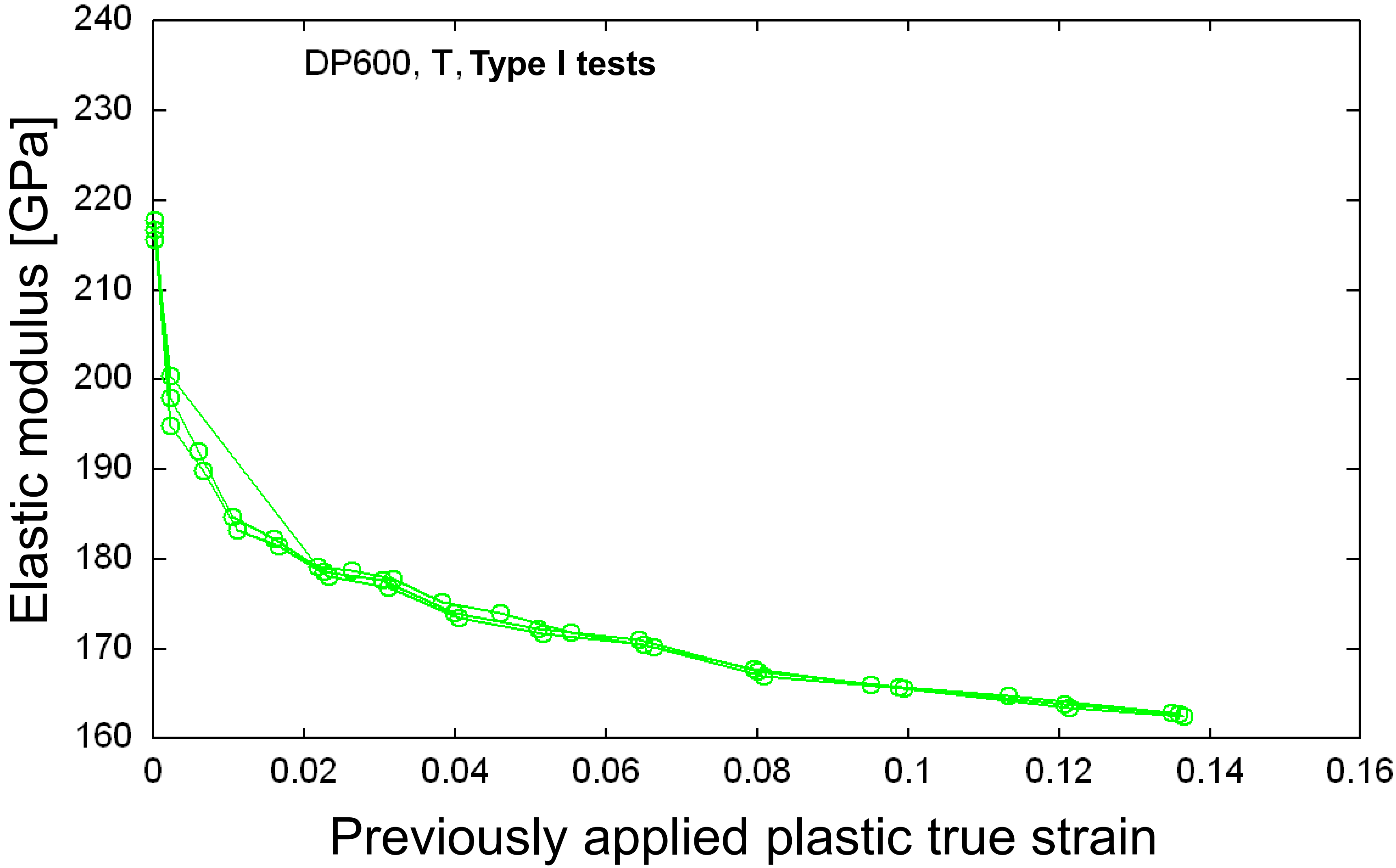
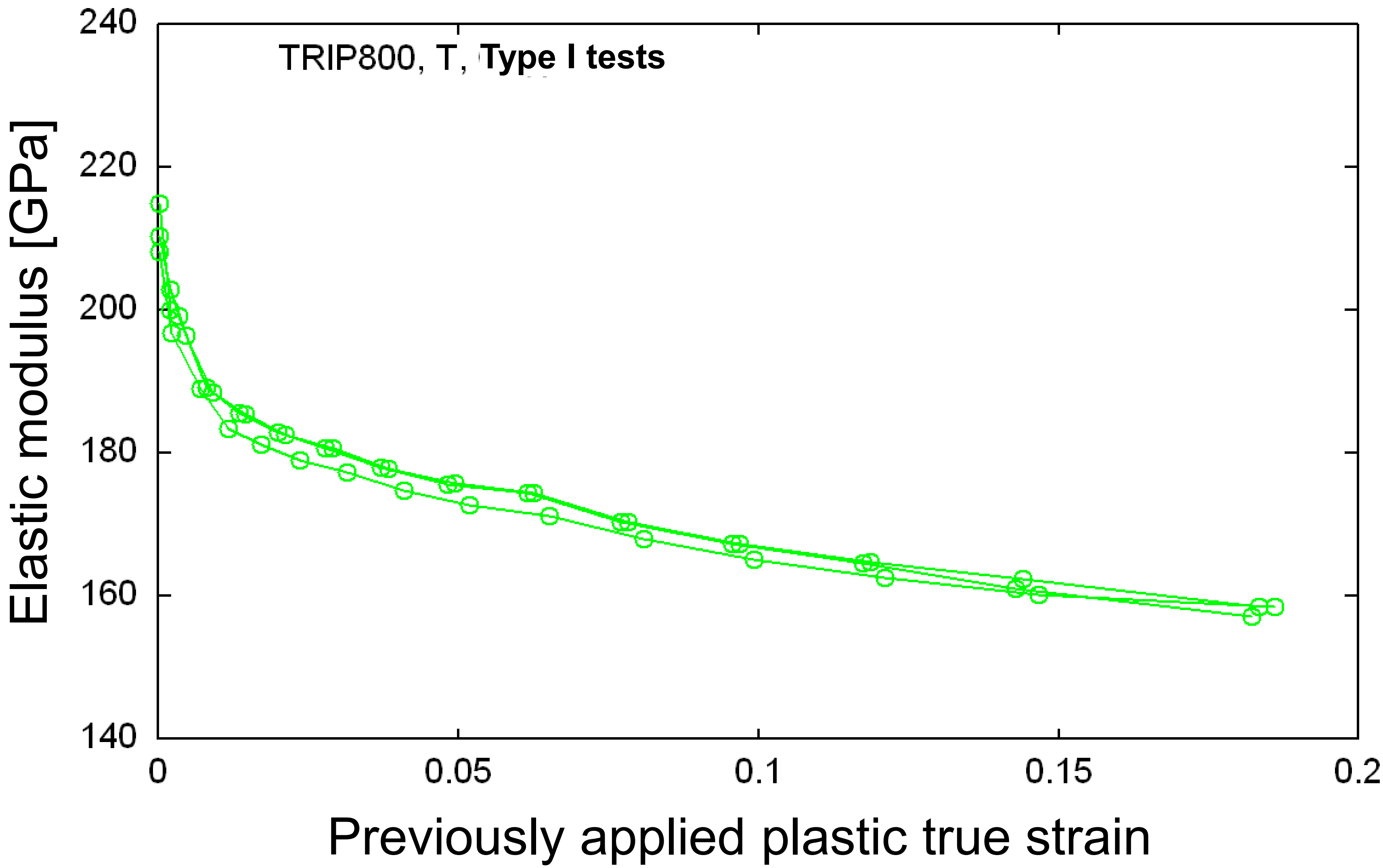
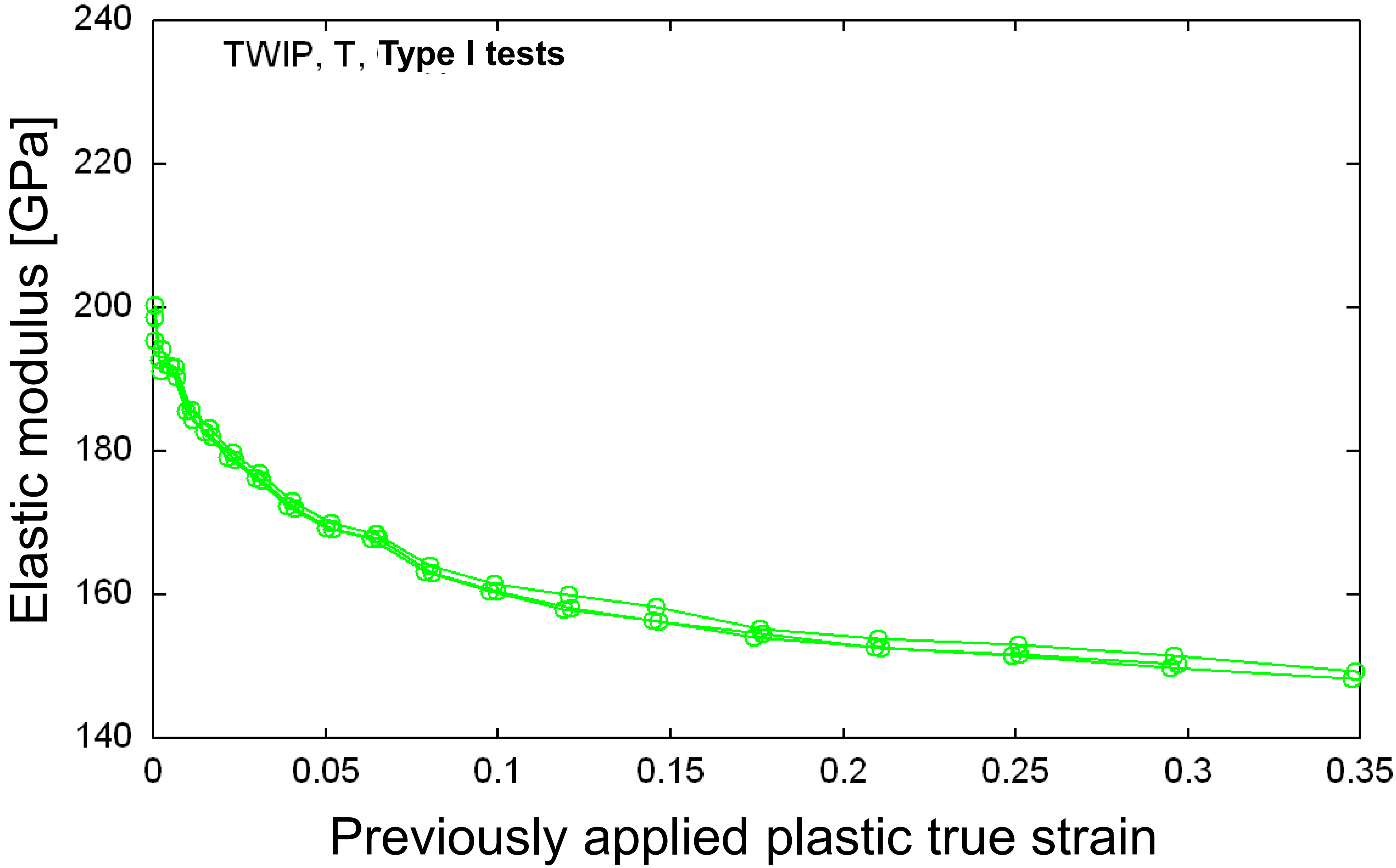


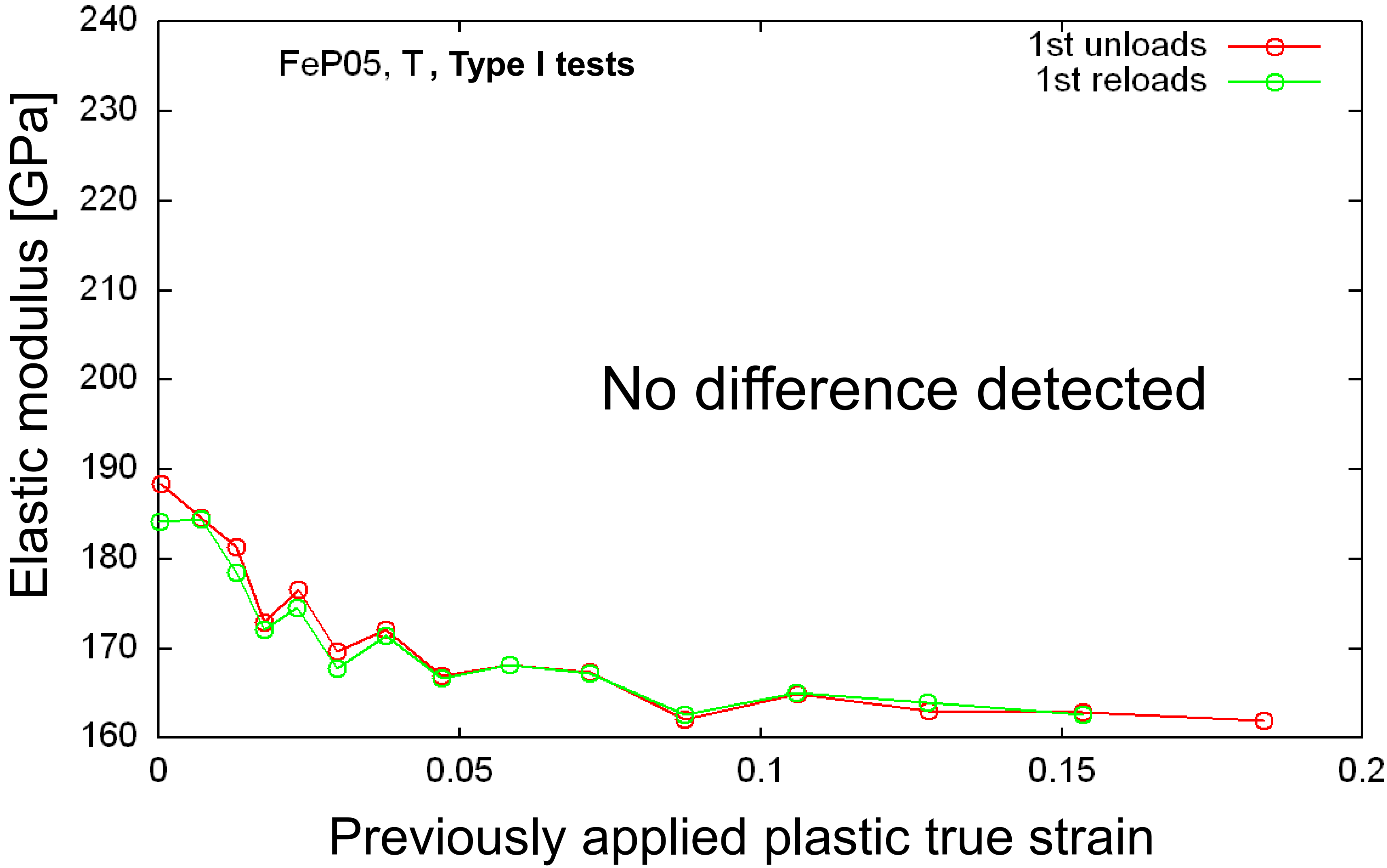
Results (2): elastic modulus of the 1st unload after the plastic prestrain (3 samples)



Results (2): elastic modulus of the 1st unload after the plastic prestrain (3 samples)



Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload



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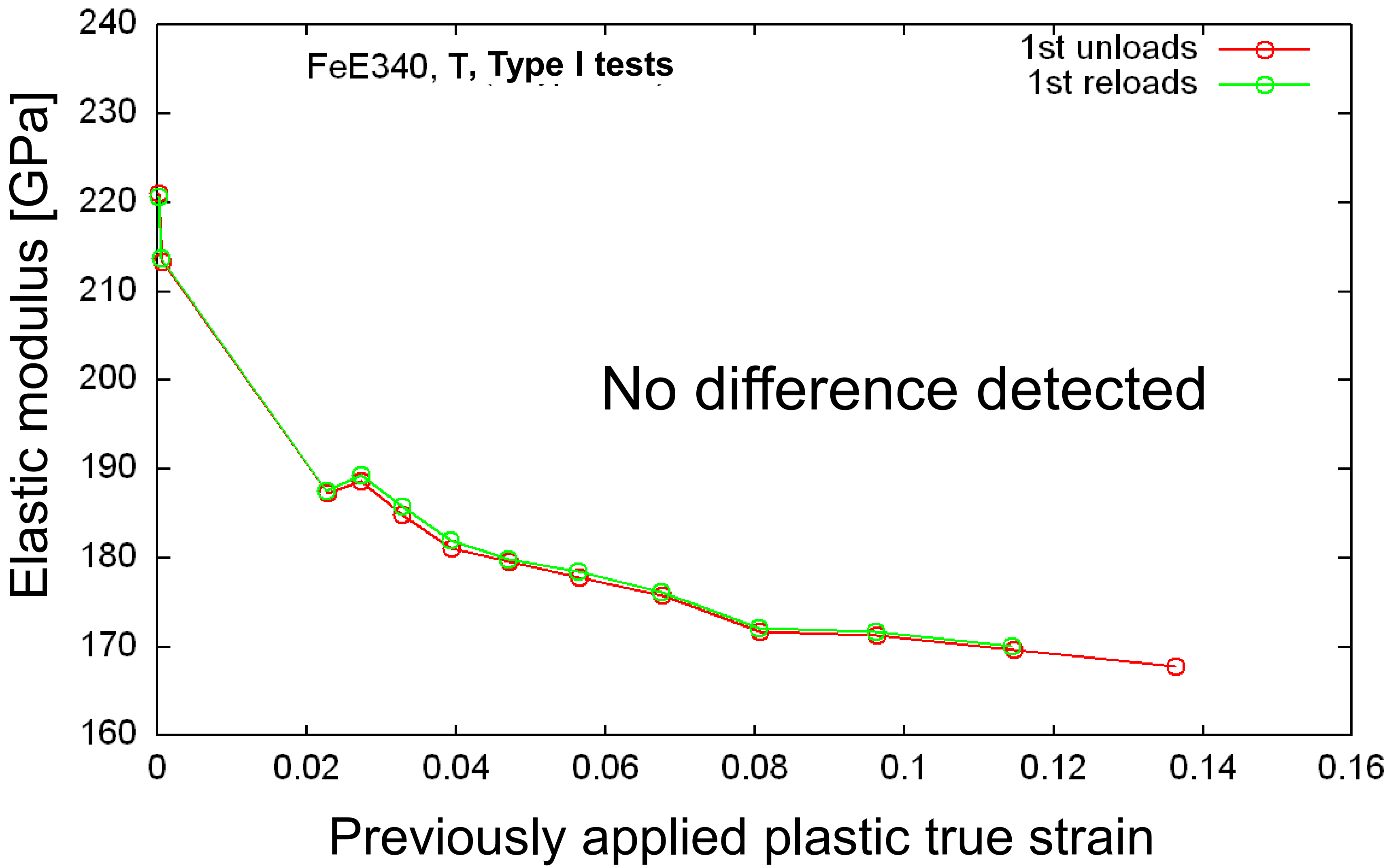
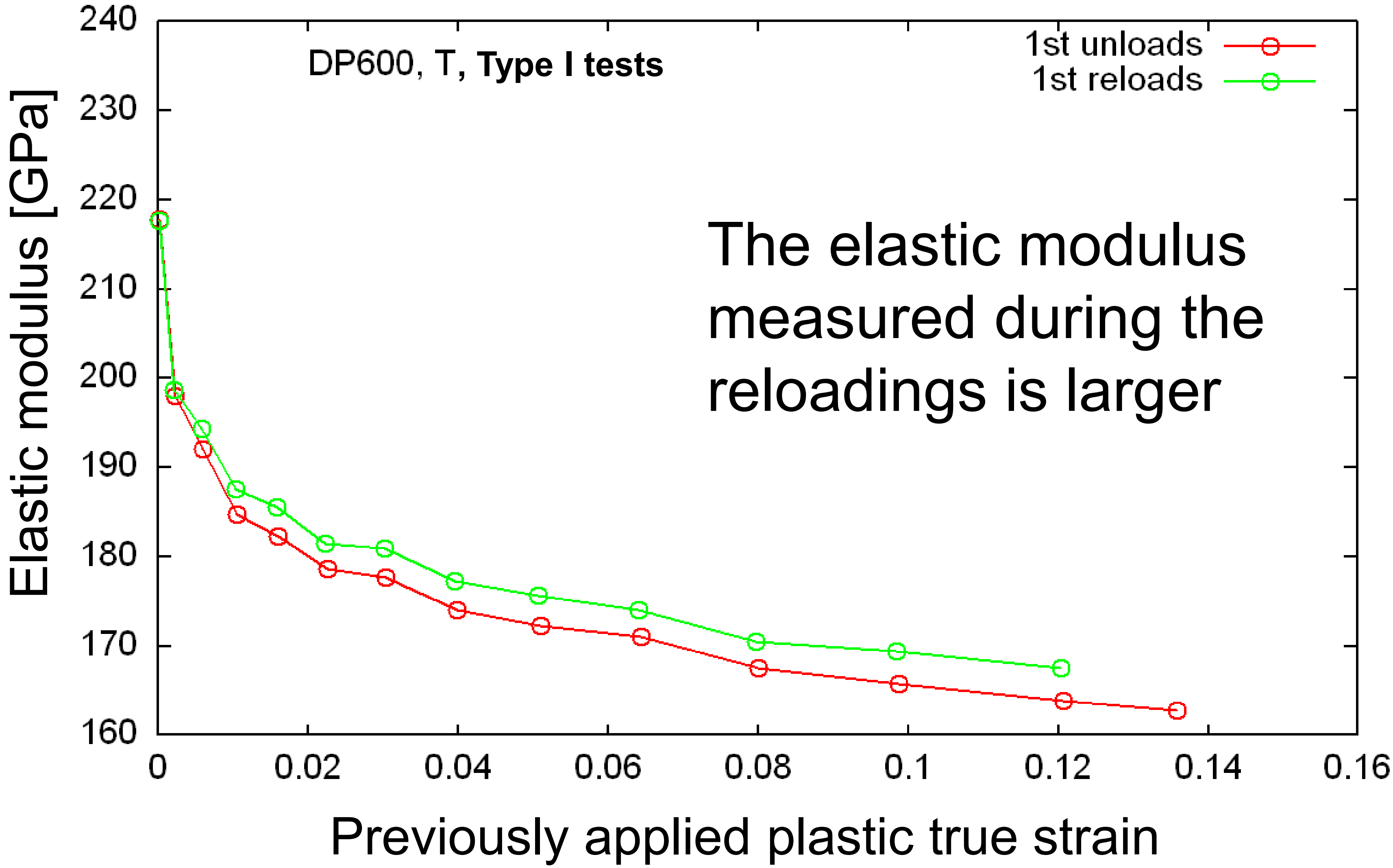
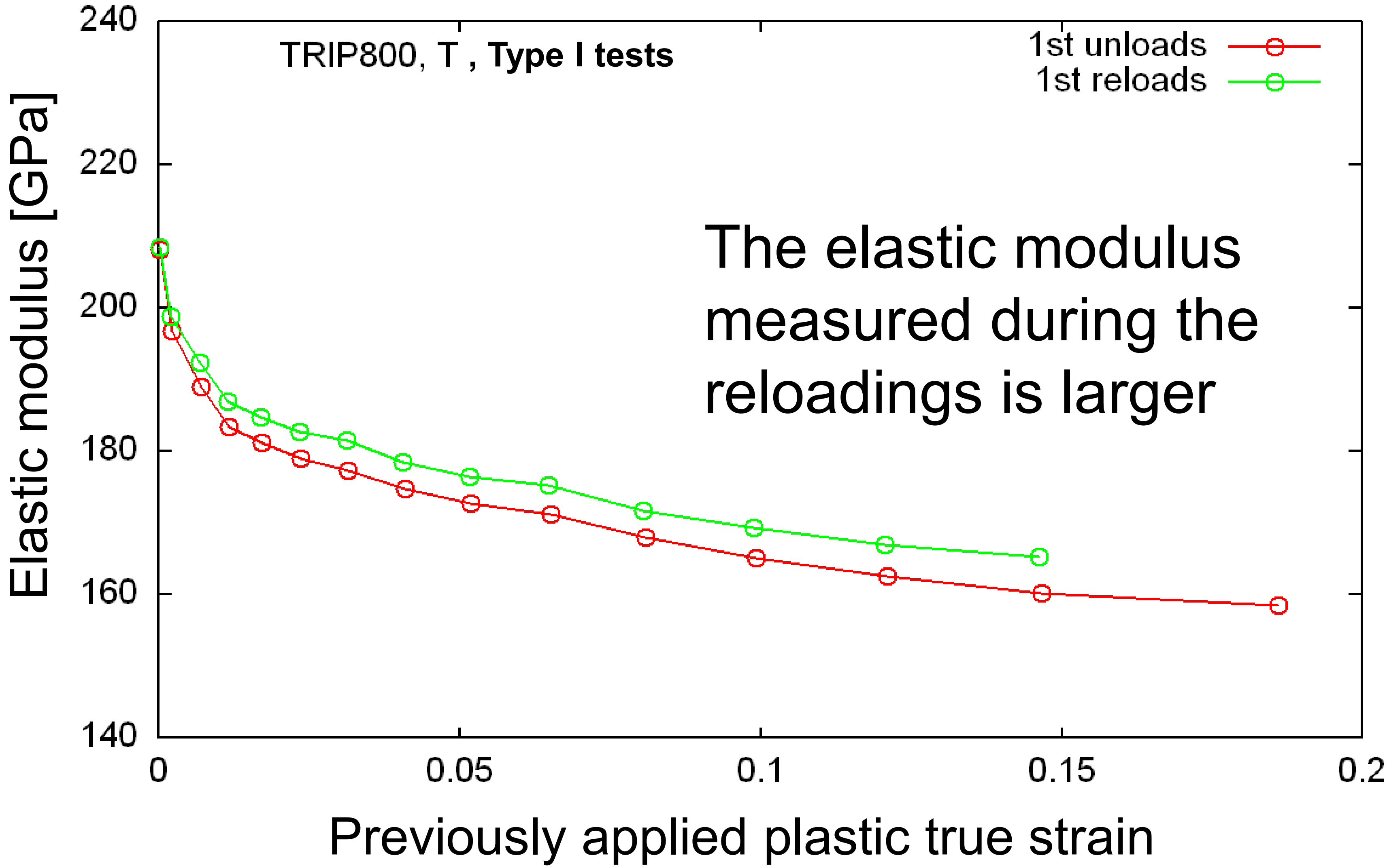


Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload

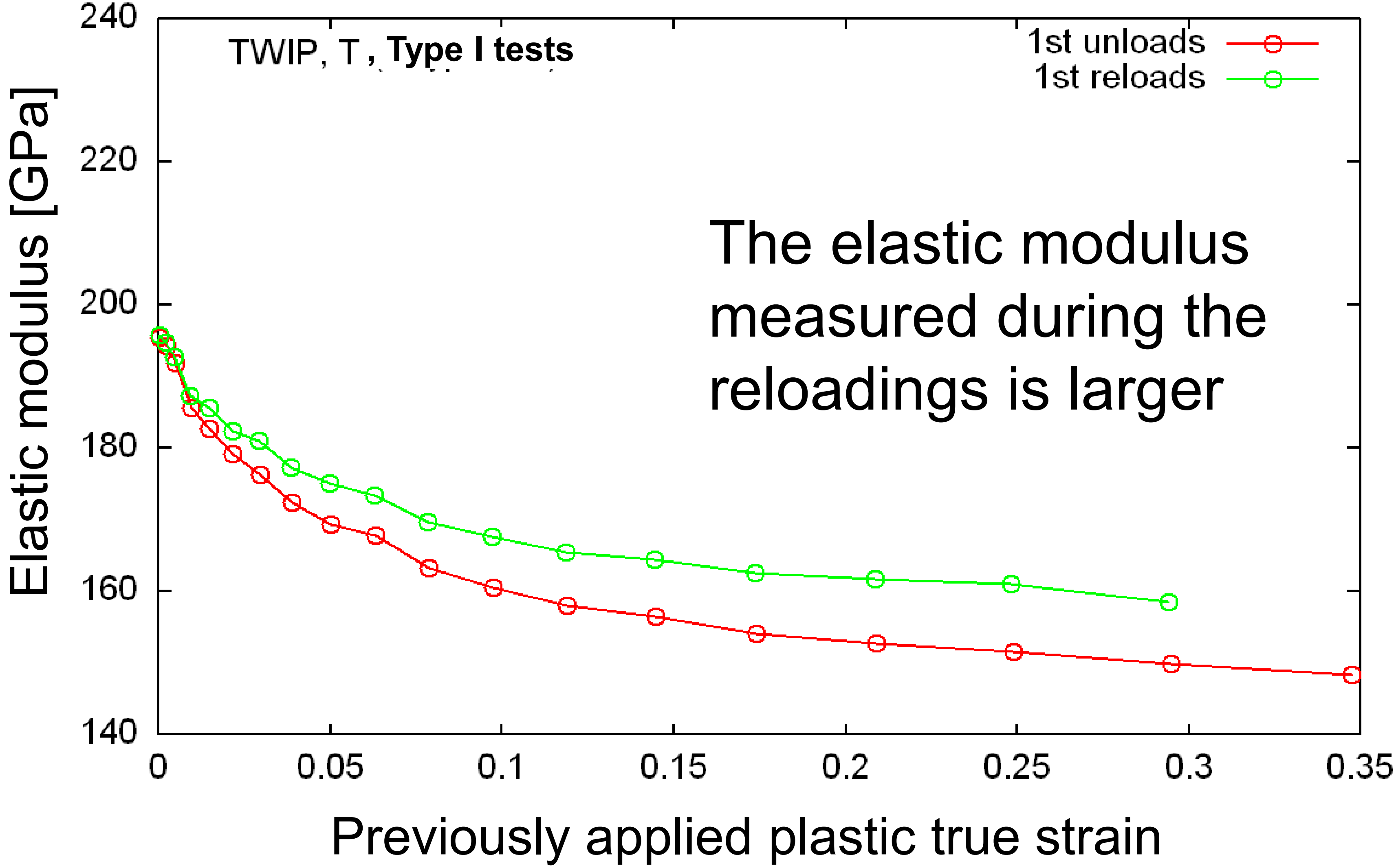


The elastic modulus measured during the reloadings is larger

Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload



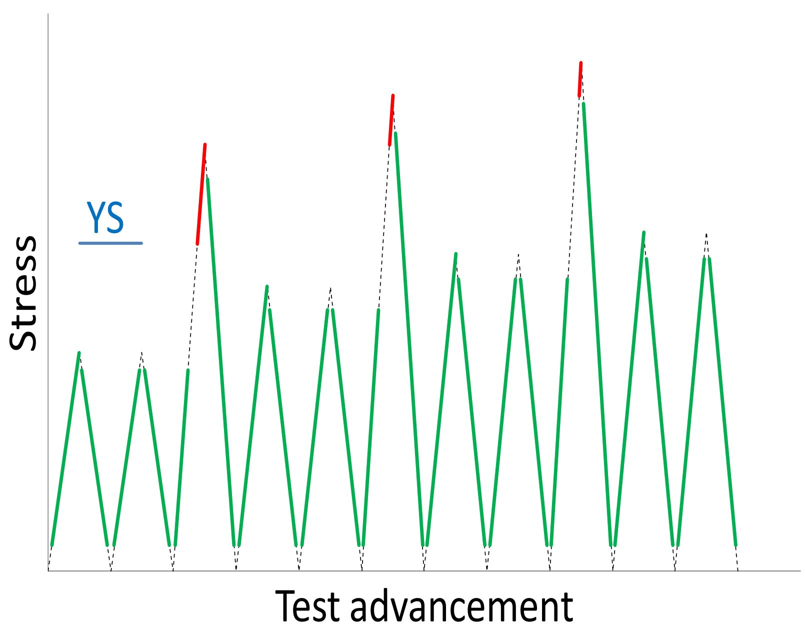
Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload

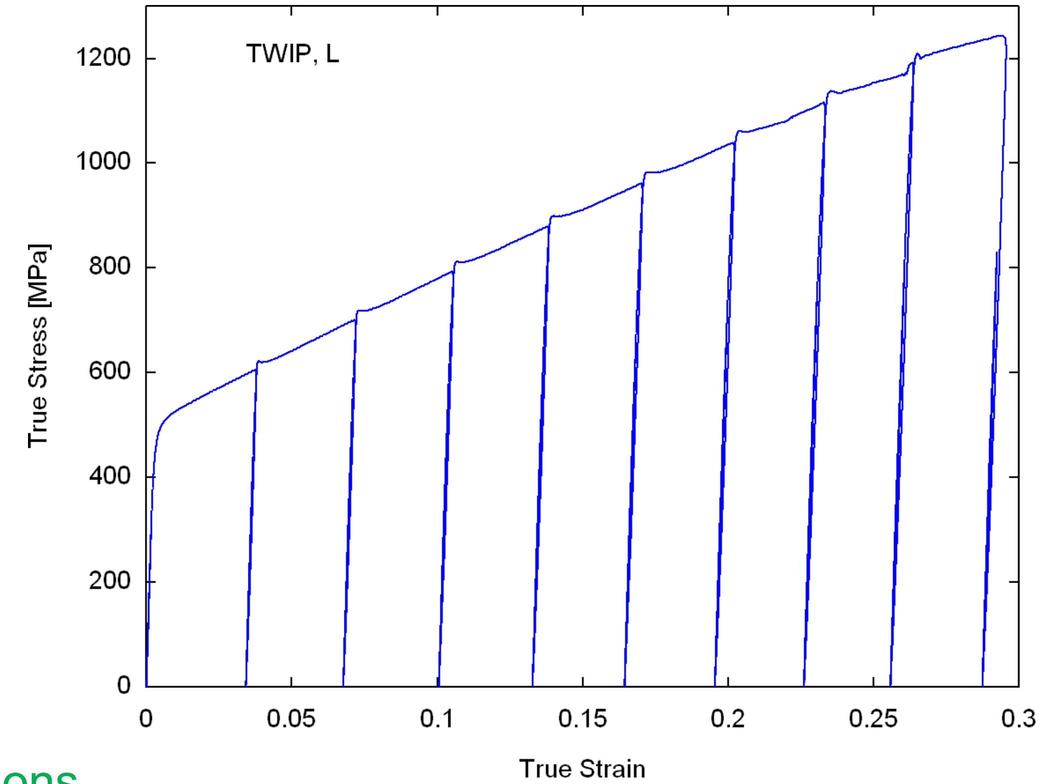


Type II tests

- repeated ≈3% true plastic strain steps
  (elastic strain rate: loading ≈10^{-3} s^{-1}, unloading ≈10^{-4} s^{-1})

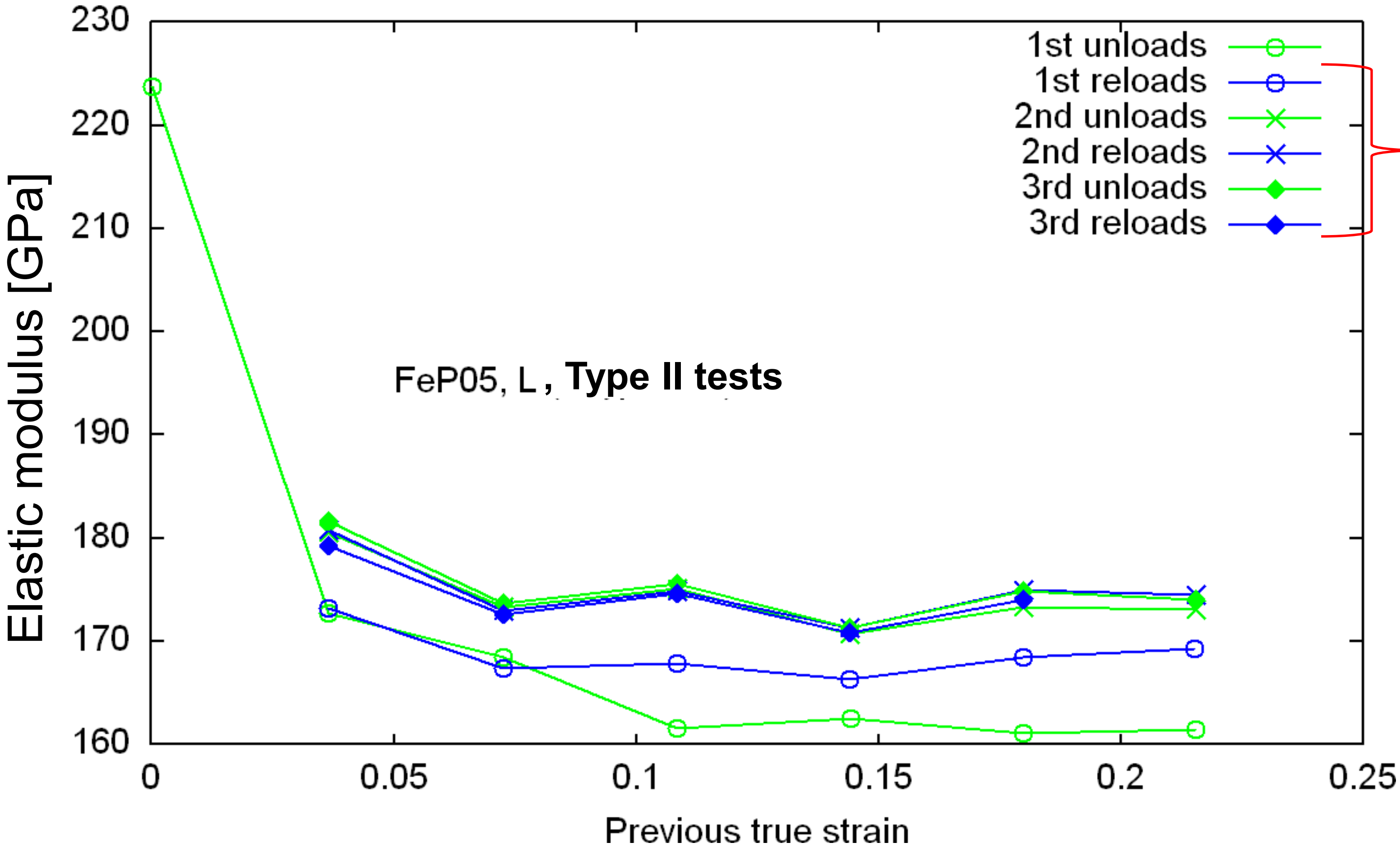
- 2 elastic unload-reload cycles at test start and after each plastic step, up to ⅔ of YS or ⅔ of previous maximum stress (strain rate ≈10^{-4} s^{-1})





green lines: elastic modulus calculations

Results (4): elastic modulus measured upon successive unloads and reloads after the plastic strain

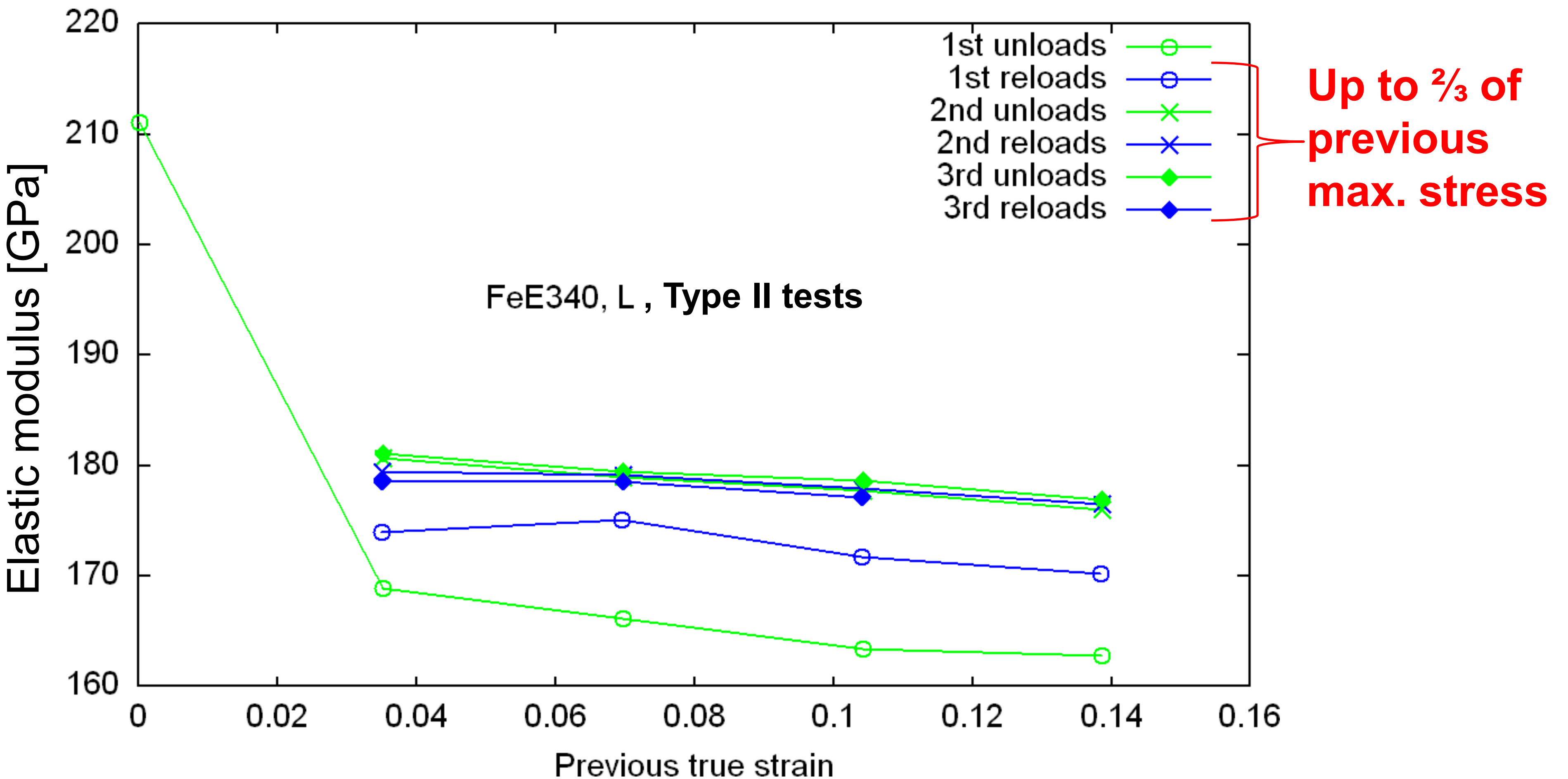


Up to ⅔ of previous max. stress

Differences are slightly broader than in type I tests, probably due to the lower reloading max. stress.

After the 2nd unload-reload cycle, an asymptote is reached

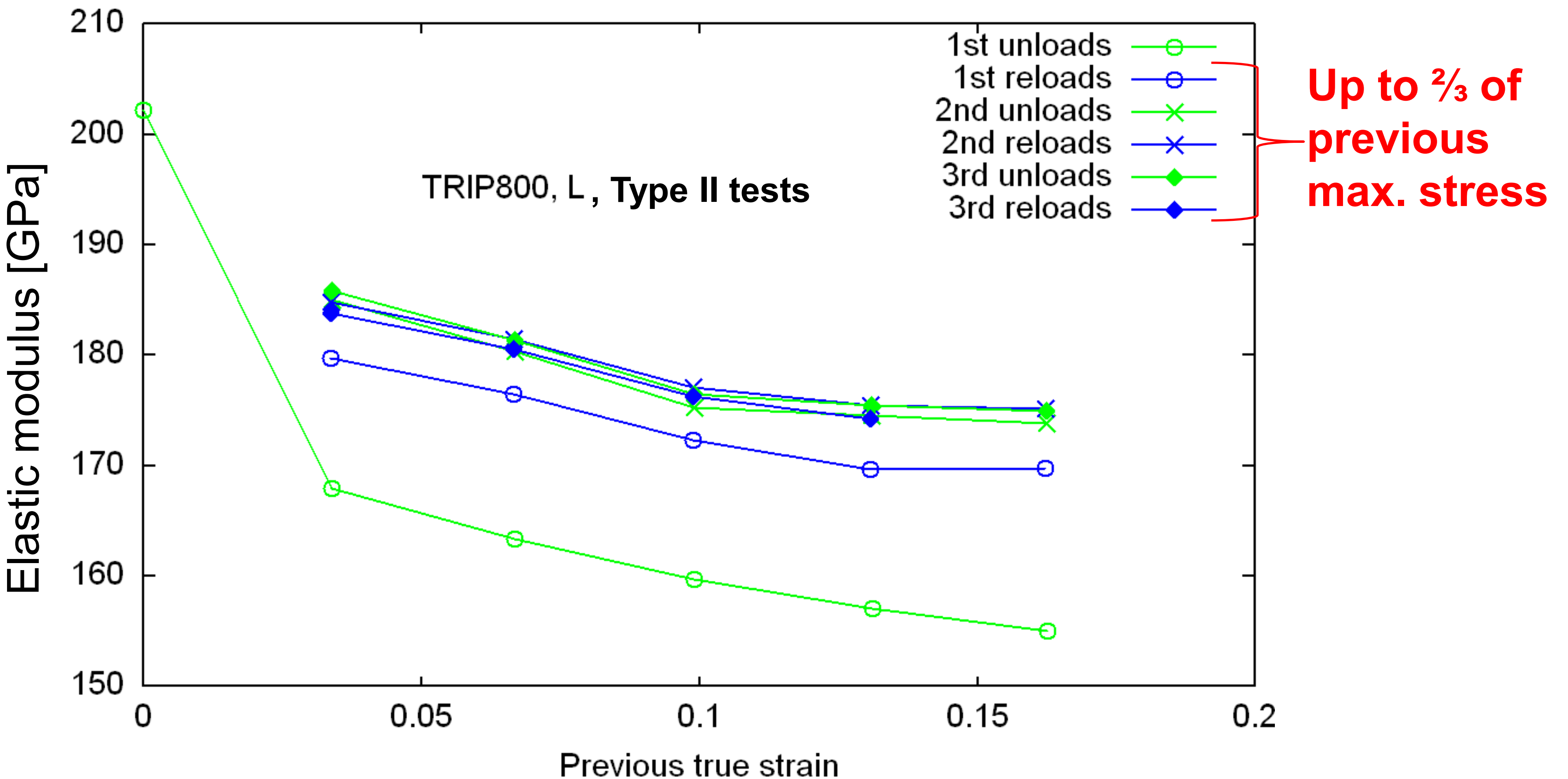
Results (4): elastic modulus measured upon successive unloads and reloads after the plastic strain



Differences are slightly broader than in type I tests, probably due to the lower reloading max. stress.

After the 2nd unload-reload cycle, an asymptote is reached

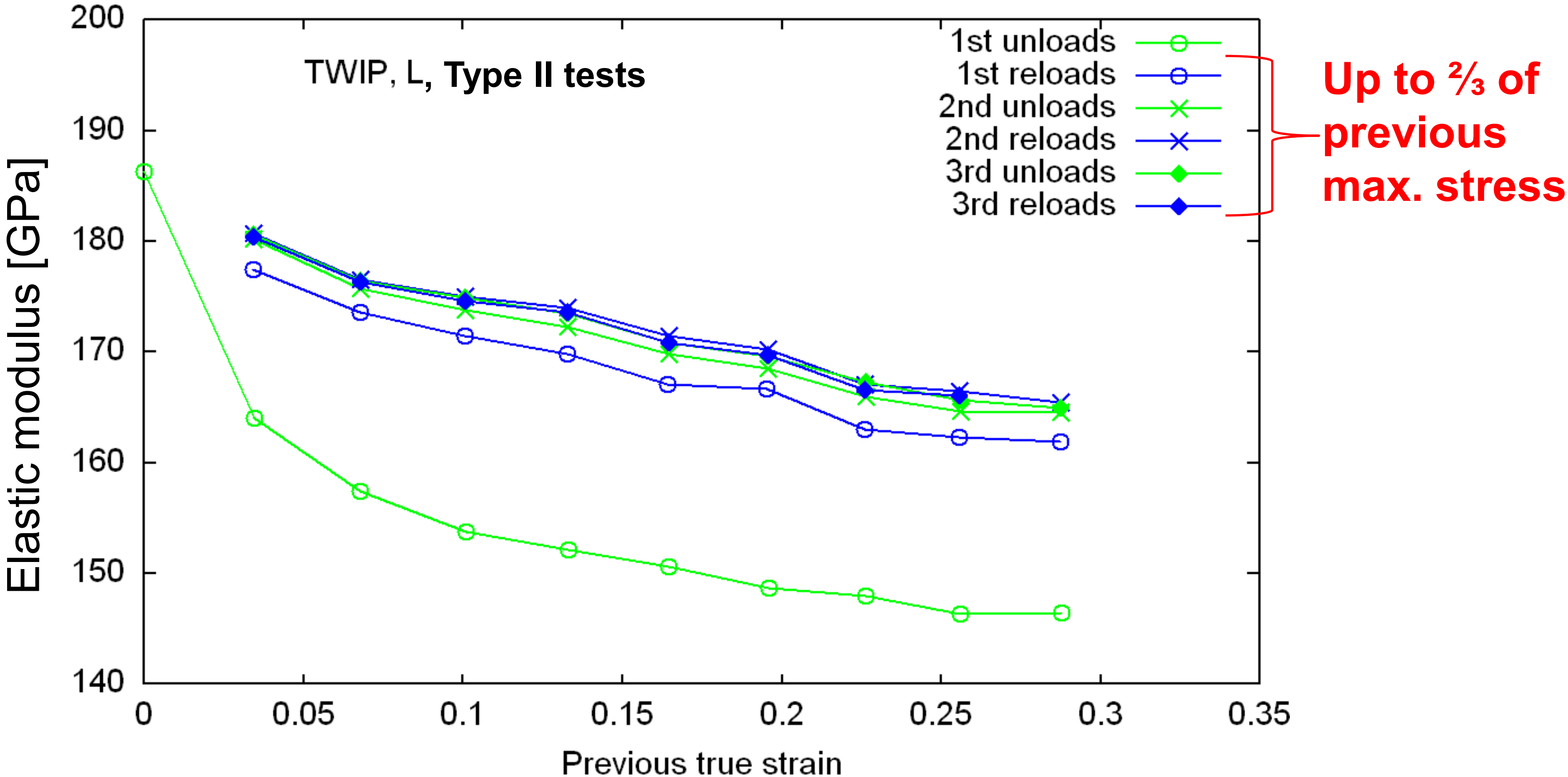
Results (4): elastic modulus measured upon successive unloads and reloads after the plastic strain



Differences are slightly broader than in type I tests, probably due to the lower reloading max. stress.

After the 2nd unload-reload cycle, an asymptote is reached

Results (4): elastic modulus measured upon successive unloads and reloads after the plastic strain



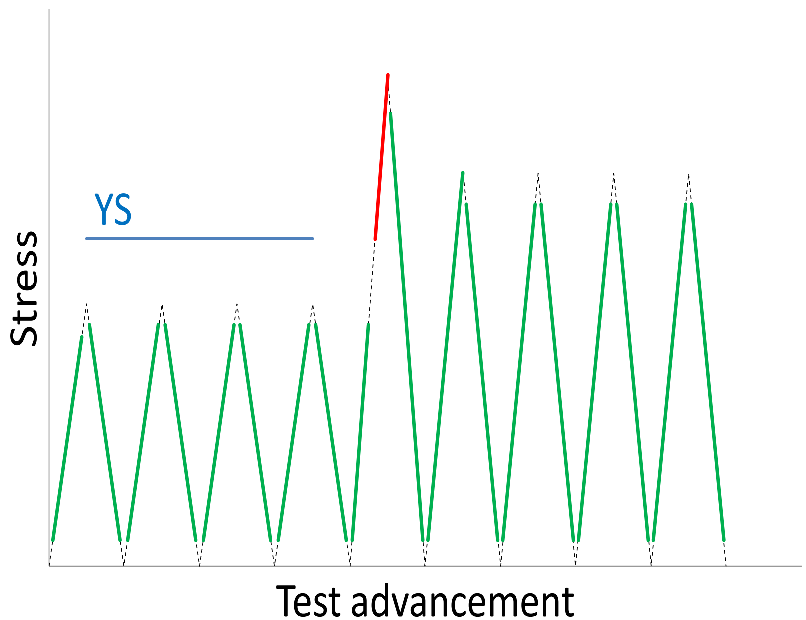
Differences are slightly broader than in type I tests, probably due to the lower reloading max. stress.

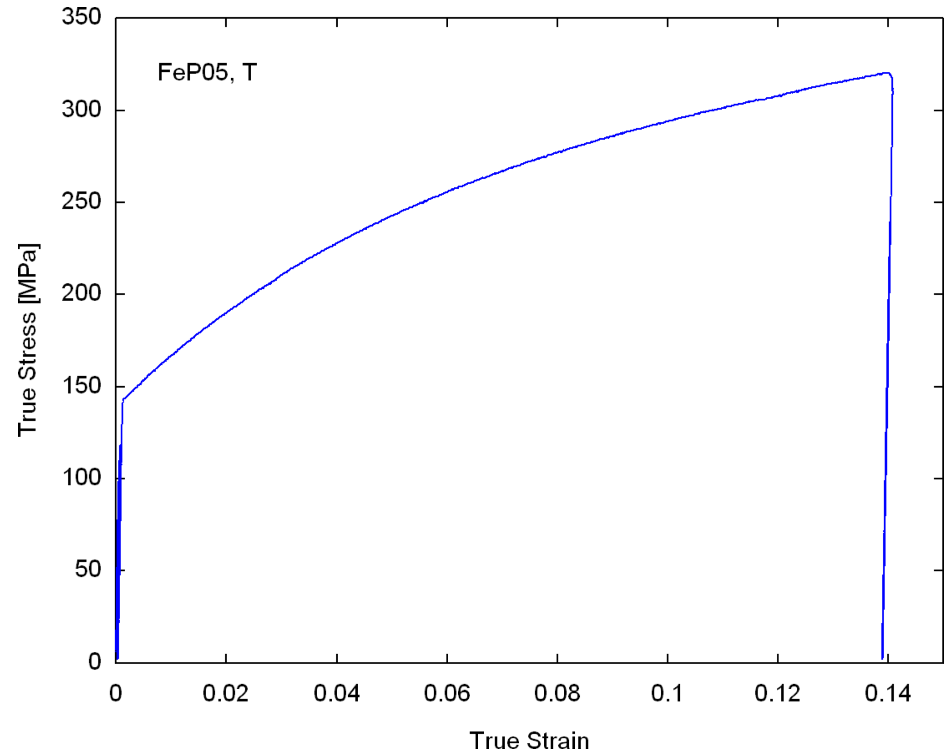
After the 2nd unload-reload cycle, an asymptote is reached

Type III tests

- one ≈14% true plastic strain step
  (elastic strain rate: loading ≈10^{-3} s^{-1}, unloading ≈10^{-4} s^{-1})

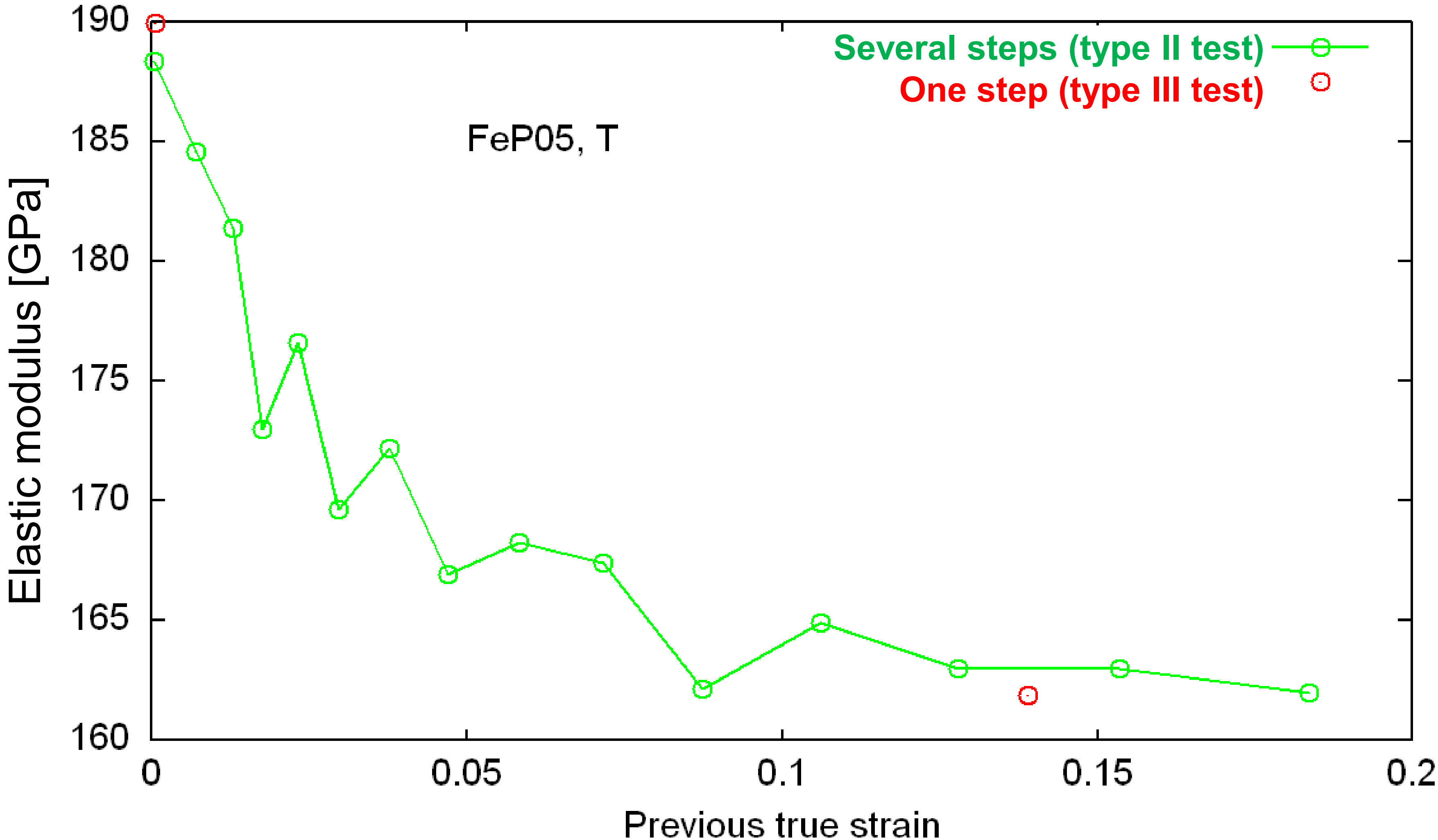
- 4 elastic unload-reload cycles at test start, up to 80% YS, and after the plastic strain, up to 80% of maximum stress (strain rate ≈$5 \cdot 10^{-5}$ s^{-1})





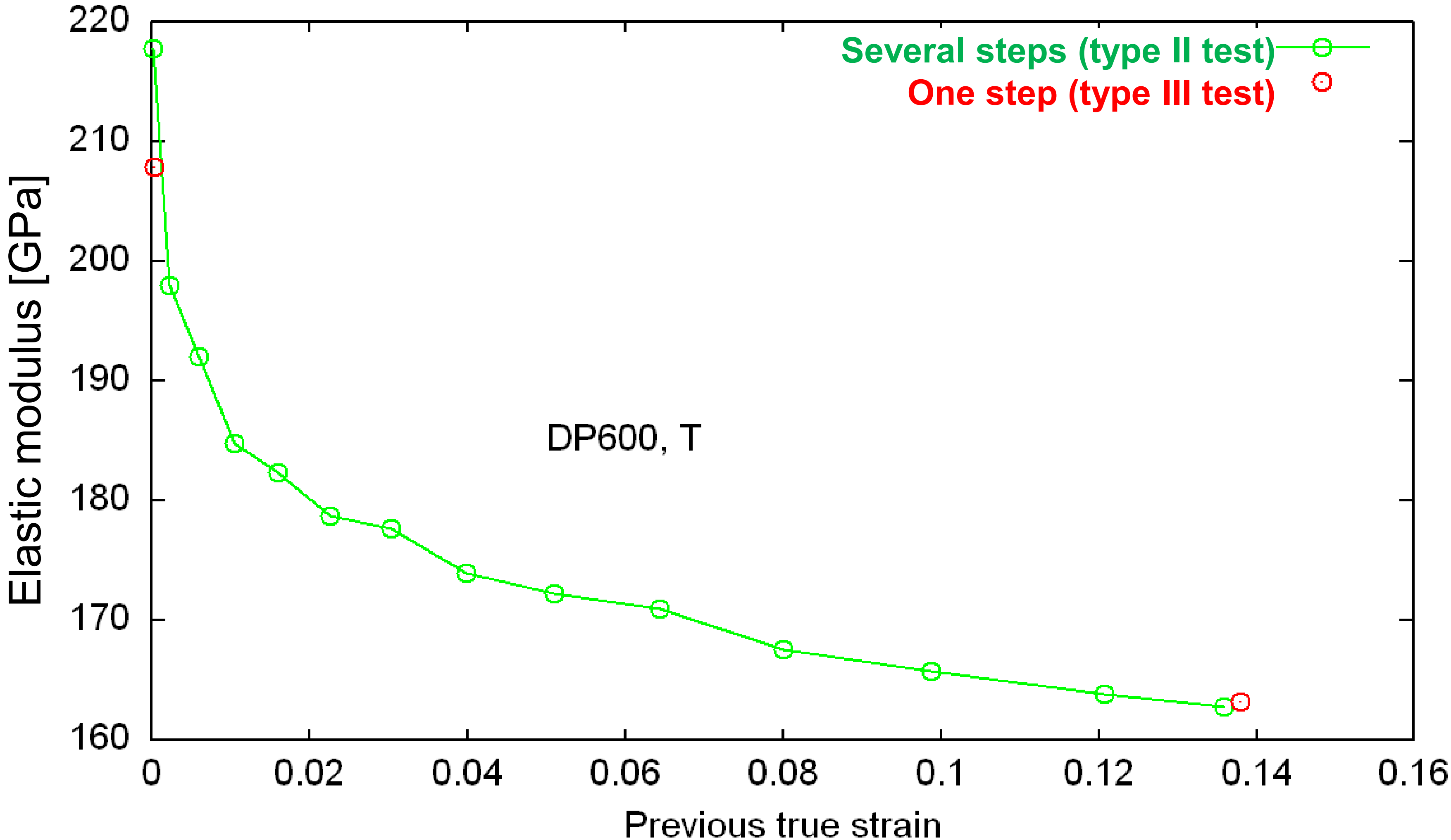
green lines: elastic modulus calculations

Results (5): elastic modulus measured after one or several prestrain steps (upon 1st unloading)



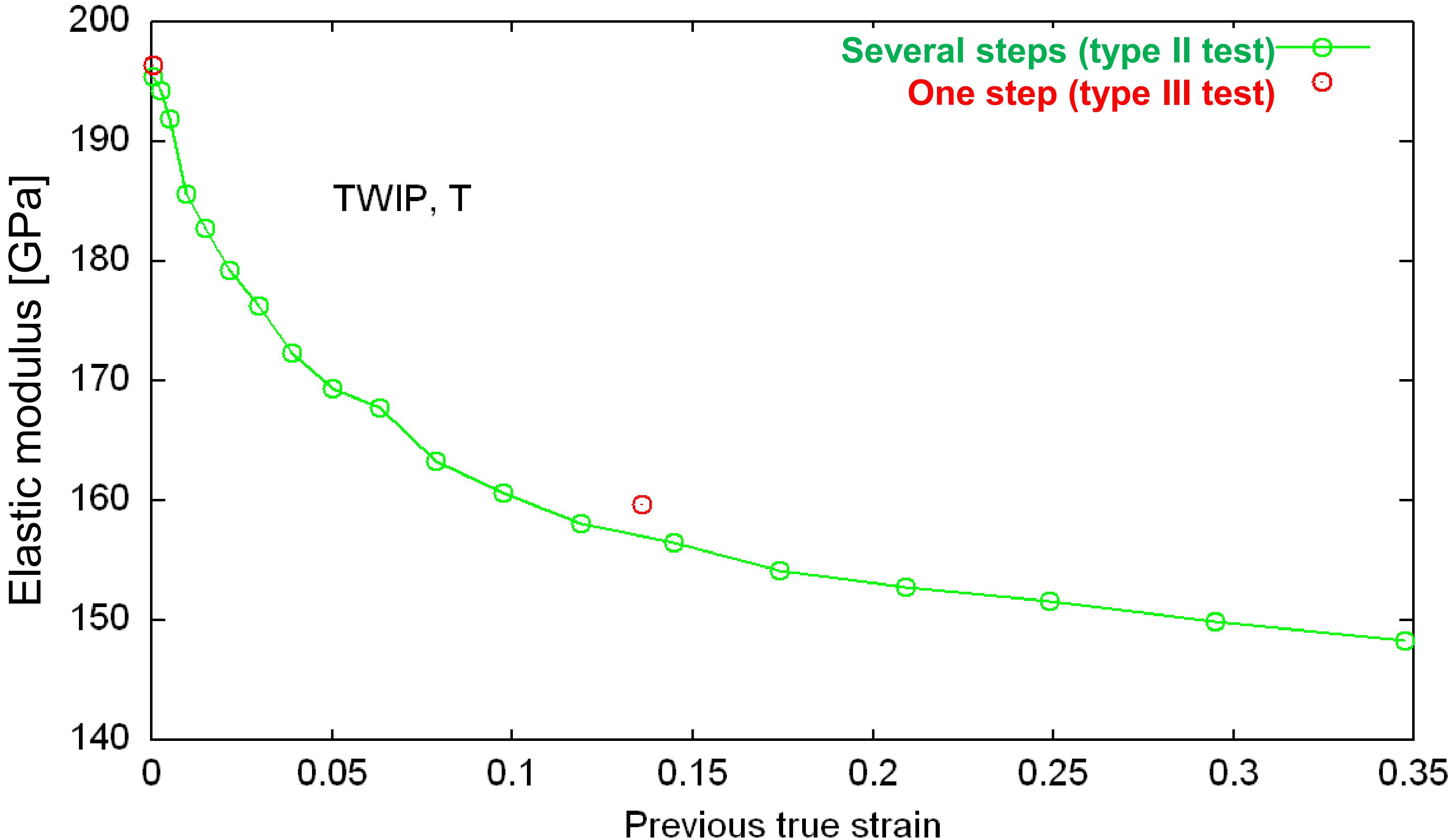
No relevant differences

Results (5): elastic modulus measured after one or several prestrain steps (upon 1st unloading)



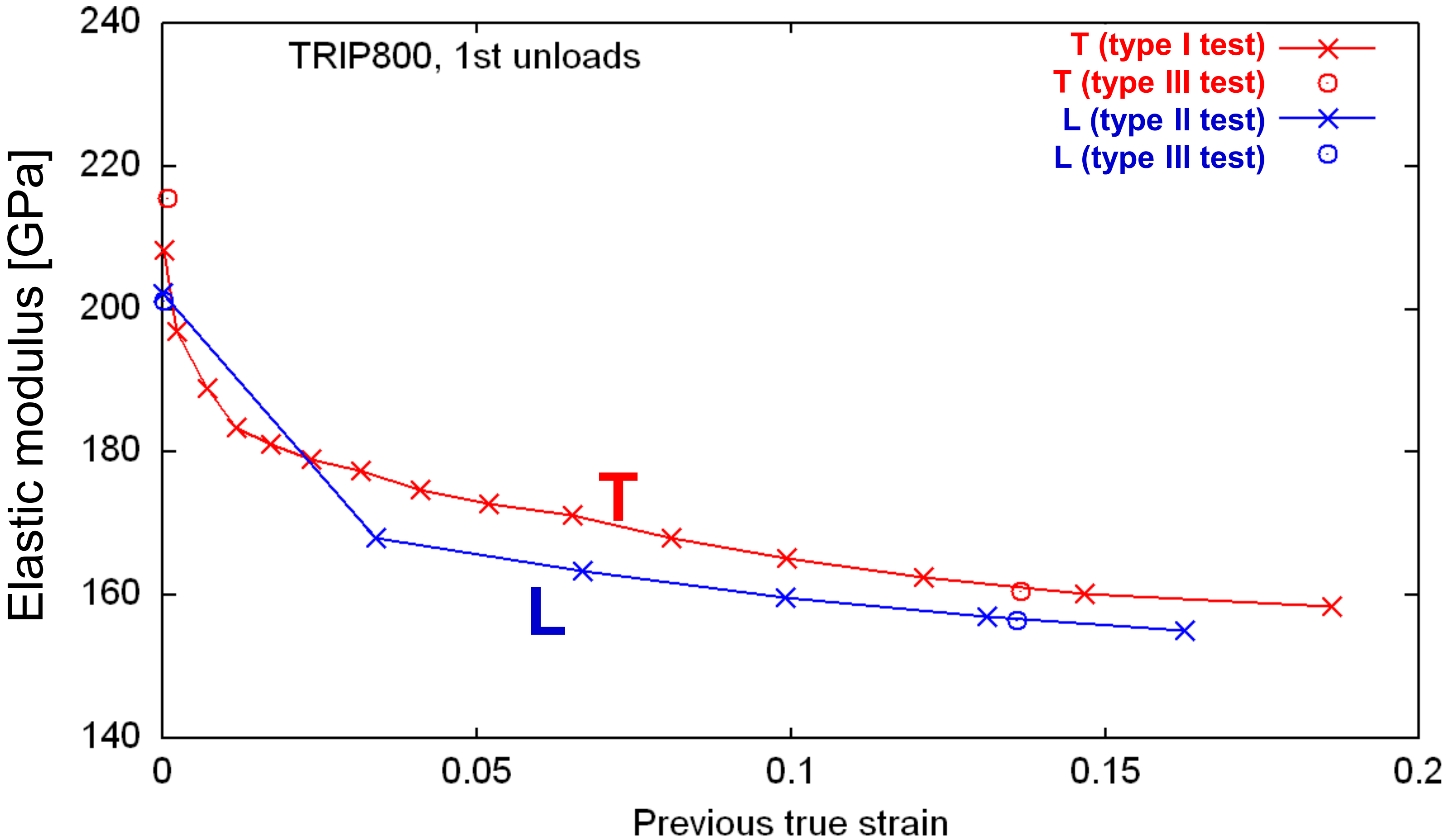
No relevant differences

Results (5): elastic modulus measured after one or several prestrain steps (upon 1st unloading)



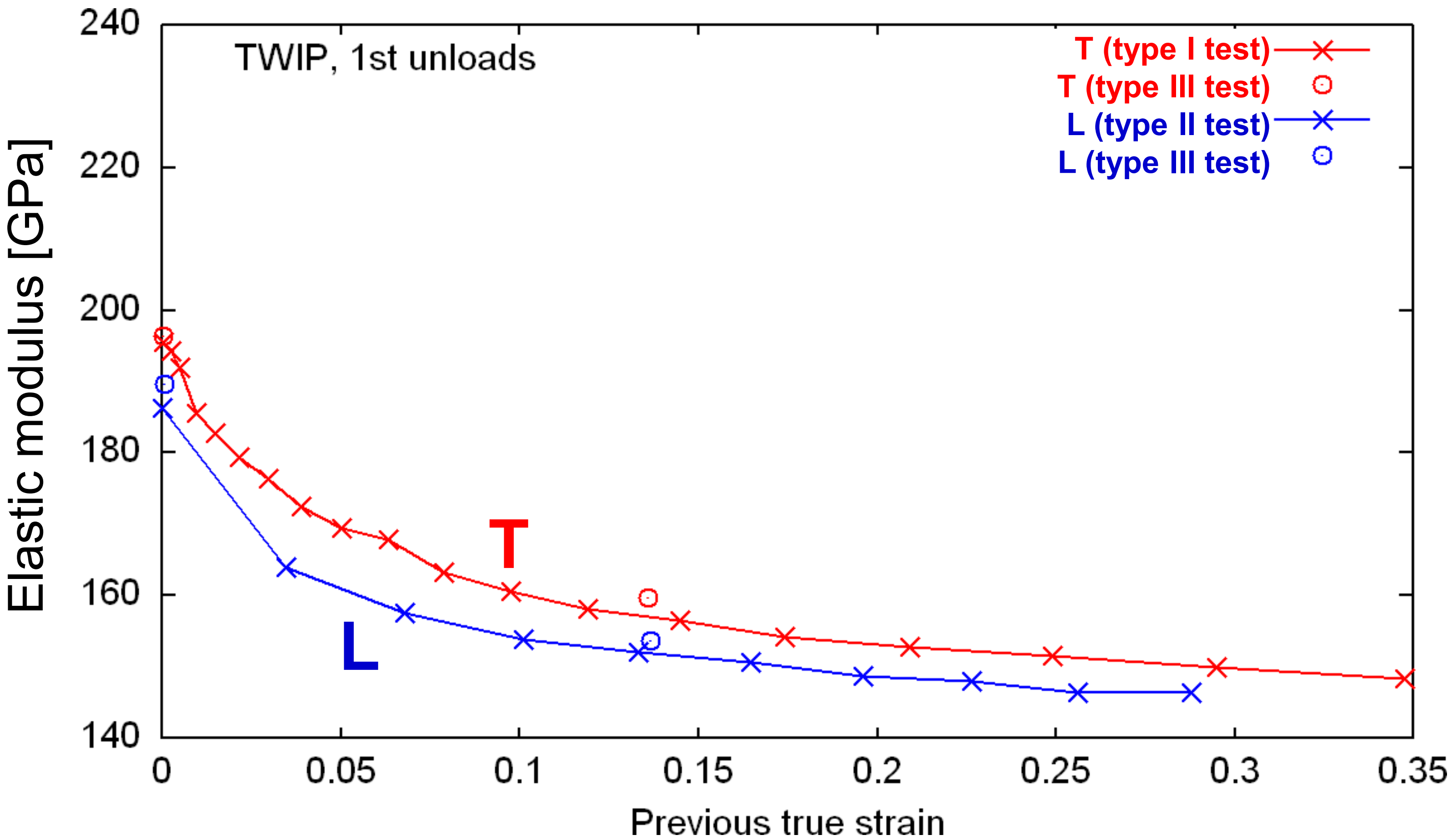
No relevant differences

Results (5): elastic modulus of specimes with T or L rolling orientations (measured upon 1st unloading)



A small difference due to the specimen orientation can be detected in most examined materials

Results (5): elastic modulus of specimes with T or L rolling orientations (measured upon 1st unloading)



A small difference due to the specimen orientation can be detected in most examined materials

Conclusions

- The elastic modulus of the examined automotive steels decreases with increasing previous plastic deformation (done at room temperature)

- If one or more elastic unloading and reloading cycles are performed after a plastic deformation, increasing values of elastic modulus are detected, until an asymptote is reached (which, however, is still lower than the modulus of the undeformed steel)

- No significant differences are detected if the same previous plastic deformation is performed in one or several steps

- Smaller differences are due to the orientation relative to sheet rolling